THE MINERAL ELEMENTS IN ANIMAL NUTRITION.

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PREFACE.

In this bulletin we present the more important of the facts commonly known to physiologists regarding the functions of the mineral elements in animal nutrition. The literature of the subject is much too voluminous to be reviewed in such an article, but we have attempted to set down the main facts which have a somewhat direct practical bearing, in such manner as to serve the student of agriculture as an introduction to this important though somewhat unfamiliar subject.

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// BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 201. JANUARY, 1909.

THE MINERAL ELEMENTS IN ANIMAL NUTRITION.

BY E. B. FORBES.

INTRODUCTION

The mineral substances which enter into the composition of animals constitute the ash, or that portion which remains after all that will burn has passed away. These ash constituents, while slight in amount, stand in a peculiar and interesting relation to the life processes and living structures of animals. We are not accustomed to hear much about them, but their functions are so complicated and important as to constitute a wonderfully interesting field for investigation by the practical scientific agriculturist. This is the field in which the soil chemist, the agronomist, the stockman, the physiologist and the average farmer all find a common ground of interest, for these mineral substances which constitute the ash of animals come from the soil through the plant to the animal, and let us not forget that Man too is an animal, and no one who is interested in either agriculture or animals or people can afford not to know about the ways in which these dead ashes from the earth become involved in those amazing processes which we see and experience as life.

Prominent among the mineral nutrients are the compounds of calcium and phosphorus. These two elements, beside being important constituents of animal bodies, are quite as important plant foods, and in the latter relation demand very prominent consideration as elements of soil fertility.

Many of our soils are benefited by liming and most of them are improved by applications of phosphatic fertilizers.

As the stores of these elements in the soil become depleted they come to be limiting factors in the growth of plants. Not only is the yield decreased but the calcium and the phosphorus content of the crops grown on soils deficient in these elements is decreased by the poverty of the soil.

Further, when these crops are used as food for animals, their low calcium and phosphorus contents become, in certain cases, limiting factors not only in the production of bone, muscle, eggs and milk but also in the maintenance of normal conditions in other fundamental physiological processes.

This chain of circumstances has already worked itself out in important practical ways in many parts of the world, especially in regions where the poverty of the soil in lime has minimized the lime content of the roughage to such extent that animals dependent upon such foods have found them incapable of supporting normal growth of the bony structures. These are among the logical consequences of a system of agriculture that is not self-sustaining, a system which leaves the soil poorer than it found it.

There are a number of reasons why our knowledge of the functions of the mineral elements in nutrition has not kept pace with our advancing knowledge along other lines. First, animals need comparatively little of the mineral nutrients in their food; second, animals' bodies contain considerable reserve supplies of the mineral nutrients which can be drawn upon in case of need, so that a deficiency of the food in certain mineral nutrients is not at once made apparent by the behavior of the animal; third, the excretion into the intestine of waste products containing mineral elements, and their consequent appearance in the feces along with undigested mineral nutrients prevents an accurate judgment as to the digestibility of the same; fourth, the redigestion and reassimilation of mineral matter from certain waste products which have been excreted into the intestine, thus resulting in a repeated utilization of the same nutrient substance, tends to obscure the facts regarding the nutrient in question; and fifth, most foods, though by no means all, even of our commonest ones, furnish as much of the mineral nutrients as animals need.

Can it be that such an important matter as the provision of the body with mineral nutrients has not been adequately provided for by natural selective processes? Have not animals' food-habits and digestive processes been adapted to the provision of the body with all those nutrients which it needs?

In a general way we may answer these questions in the affirmative, but when we consider them with care we see many exceptions and qualifications becoming necessary.

It is doubtless true that in his aboriginal state Man's food habits provided his body with all those nutrients which his simple life required, but civilization has set up new standards, unnatural ones in the sense that natural selection has not been able to accomplish new adaptations as fast as they were required by changed habits and so we find ourselves living somewhat out of harmony with our physiological processes.

Civilization requires specialized efficiency, and so the organism is put upon a strain by the severity of the tax upon some functions; certain it is that the twentieth-century American has need for more food of a sort capable of developing his nervous system than had aboriginal Man. Indiscriminate eating may sustain life at low-pressure, but keen competition and highly specialized activity call for definite adaptation of the food, both as to kind and quantity, to the necessities for nutriment.

As this subject relates to stock feeding we find that modern tendencies give it a special importance that it had not in times past. The forced feeding of our early-maturing meat animals and the selective improvement of our poultry and our dairy cows for greater productive capacity call for a higher percentage of mineral nutrients in foodstuffs than was necessary in the old days of less intense production. The requirement of mineral nutrients for mere maintenance is slight in amount, compared with the requirement for the production of flesh, eggs and milk, and hence the more efficient the producer, the higher must be the ash content of the food.

There is a prevalent idea that the mineral nutrients are present in all our foods in superabundant measure, and that therefore the study of this matter is not practically important. This idea, however, is far from the truth. The subject of mineral nutrients is one that will be with us, in a practical way, as long as we shall raise live stock. There are a great many foods that lack some of the mineral nutriment that animals need but this subject is of greatest practical importance as it relates to the feeding of Indian corn.

If it was ever true that in our natural choice of foods we could not fail to get an abundance of those mineral nutrients which an animal needs, it ceased to be true with the advent of modern processes of milling and preparation of foodstuffs and with the selective improvement of our live-stock for rapidity or efficiency in the production of growth, milk, eggs or wool.

SPECIFIC EFFECTS OF FOODS.

Every herdsman knows that foodstuffs have characteristic or specific effects upon animals. A steer which has been fitted on corn looks, feels and *is* different from one fitted on a mixture of small grain feeds. The herdsman also knows that some foodstuffs, at least, have characteristic effects upon the breeding capacities of animals.

There is among experienced stockmen a considerable fund of tradition and opinion regarding these matters but the difficulties in the way of getting at the real facts, in a clean-cut way, are so great that we find the talent disagreeing, often vehemently, upon most important and fundamental considerations.

These specific effects of foods are due in part to relative proportions of carbohydrates, proteids, fats, and mineral nutrients and also in part to differences in the chemical compounds included under these headings. The specific effects of natural foods is a subject of direct interest to farmers; the specific effects of nutrient compounds constitutes the simplified problem which the investigator must solve before he can say just why natural foodstuffs produce their particular effects.

Let us consider the extent to which different kinds of carbohydrates, proteids, fats and mineral nutrients* may affect animals differently.

Carbohydrates are used in the body mostly for the production of energy and for the composition of fats, glycogen and milk sugar. All nutrients used for the production of energy yield it through the same process, the union of their carbon with oxygen supplied by the blood. There can be no specificity in these matters except as to *amount* of energy produced. Glycogen and milk sugar are definite and comparatively simple compounds. We cannot imagine that different foods vary them in any way; and fats produced by carbohydrates are characteristic only of the animal producing them.

Proteids are used (1) for the production of energy, in which case they are simply oxidized, and (2) for the construction and repair of proteid tissue.

* Throughout this article we refer to the mineral constituents of plants and animals by the names of the elements, or by the names of the compounds in mind; we do not follow custom in recording mineral elements as their oxides, and then calling these oxides by the names either of the elements, their hydroxides or their acids. In physiological discussions, at least, it is imperative that we call the compounds in mind by the names which belong to them.

To calculate the oxides to the elements use the following factors:

SO_3 x .4004=S
P_2O_5 x .4366=P
Fe_2O_3 x .6996=Fe
MgO x .6036=Mg
CaO x .7148=Ca
Na_2O x .7423=Na
K_2O x .8303=K

Proteids are made up of very large and exceedingly complex particles or molecules. Each molecule consists of a considerable number of definite constituent groups of atoms into which it can be separated.

Let us liken a bit of protein in an animal cell to a wall in a building. Suppose the wall is to be built from fifty different kinds of brick arranged in a definite pattern which is repeated over and over throughout the structure.

So is the bit of protein composed of a considerable number of primary groups in definite amount and definite arrangement. We can isolate and study these primary constituents or splitting products.

Let us liken each food-proteid to a load of various sorts of brick for our wall. In the digestive process the food-proteids are separated into their primary constituents, just as we might assort our load of brick, laying aside to put into our wall as many as belong to our set of 50 kinds and the odd ones, the misfits, being thrown out for other purposes.

These assorted brick are built into the wall, each of the fifty kinds being used in definite number and laid in a pattern to suit the architect.

Just so in the process of building up proteids in the body, synthesis we call it, the splitting products of the food-proteids are rearranged and reunited in particular ways and definite proportions in a manner characteristic not only of the species, but also doubtless of the individual animal.

The builder does not make the brick which he lays in the wall. He buys them from a brick maker. Neither do animals synthesize the primary constituents of the proteids from inorganic compounds. Plants only can perform this work. Animals do synthesize proteids, however, from their primary constituents or splitting products.

Now the exact composition of the proteids of an animal is probably its most fundamental characteristic. Before food-protein can be built into the body as living substance it is torn apart and built up again with such exactness and infinite particularity that the smallest details of inheritance are worked out in the proteid tissues built up by the animal from its food. It is inconceivable, in the light of present knowledge, that the food-proteids have specific influence in the formation of living body-proteids, in the sense that the animal tissues formed will possess different characteristics in accord with the particular food-proteids which have entered into their composition, though a given food-proteid may, because of its constitution, be able to form only certain ones of the body-proteids.

Turning to the fats, we find that the chemical character of animal fats is somewhat influenced by food-fats, that some food-fats do not entirely lose their identity in the digestive and assimilative processes. This is apparent not only to the chemist but also to other observers, through the appearance, feeling, taste and odor of the products in question. The market value of certain animal products, bacon for instance, is greatly affected by the direct influence of food fats upon the animal fats.

Fat, however, is not living substance. It provides warmth through preventing radiation and when oxidized liberates heat and other forms of energy, but no particular kind of fat in the food can serve any physiological function that another fat cannot be made to serve. Further than this, fats and carbohydrates are practically interchangeable as nutrients, since either can serve the purposes of the other.

Thus by process of exclusion we arrive at the conclusion that physiological specificity is a property especially of the mineral nutrients, though the relative amounts of proteids, carbohydrates and fats and the mechanical character and palatability of the foods produce less fundamental specific effects, but that fats and in a sense proteids also must share with the mineral nutrients the credit for exercising specific influence in the *structure* of the body, meaning to distinguish between physiological action and chemical constitution.

We do not fail to recognize the importance of enzymes, alkaloids, nitrogenous extractives, organic acids, etc., but consider them as outside the field of this article since they do not as a rule, contribute largely to the important effects of ordinary foods.

In the author's experiments* with swine certain facts have been demonstrated which show specific effects of foods. As a foodstuff corn is lower in protein, calcium and phosphorus than the other grain foods used in this country for live-stock. The proportion of phosphorus to protein, however, is not particularly low. Its most marked characteristic is its deficiency in calcium, which is so necessary to the growth of bone.

Corn, alone, as a hog food, when compared with rations containing more of the above-mentioned nutrients, is much less palatable, produces much less gain in weight and develops an undersized, fine-boned, over-fat animal, characterized by proportionately small kidneys, lungs, heart, liver and muscles and by high percentage of fat, inside and outside the carcass and throughout the muscles.

* Bul. 81, Mo. Agr. Exp. Sta.

The muscles themselves, in corn-fed hogs, are low in moisture content and in ash, because of the high percent of fat, but the fat-free meat is high in moisture and the fat- and water-free meat is high in ash, this excess doubtless being carried by the liquids contained in the flesh.

Comparing rations of corn alone with specially prepared experimental rations containing more protein and calcium but less phosphorus in proportion to protein, the corn rations proved to be less palatable, less efficient to cause gain in live weight, in muscles, in most of the internal organs and in the ash and strength of the bones. It was more efficient to cause fattening than gain of any other sort.

The phosphorus content of the meat as a whole and of the protein in the meat and of the ash was high, in accord with the higher proportion of phosphorus to protein in the corn rations. This modification of the composition of the ash of the meat was doubtless due to the mineral substances in the liquids of the flesh.

The low protein and low calcium content of the corn affected the bones injuriously as was shown by their small size and low breaking strength.

The specific effects of the water-extract of wheat bran were also studied because of the mineral nutrients which it contains. This preparation was found to contribute conspicuously to the size and breaking strength of the bones and to the development of the muscles, heart and lungs, when compared with a ration not containing the bran extract and on this account lower in calcium and phosphorus in proportion to protein, the *amount* of protein not differing greatly.

The muscles of the pigs receiving this bran extract were lower in phosphorus than the muscles of the other lots, though the pigs receiving this feed had made maximum increase both in the weight of the muscles and also in the total protein of the muscles. The phosphorus of the bran extract was present mostly as salts of phytic acid, a complex organic compound.

Bone meal, when added to a ration which was low in calcium and in phosphorus, greatly increased the ash and strength of the bones, but did not increase the percentage of protein in the growth produced; in fact there was a slightly smaller proportion of spleen, lungs and muscles in the increase produced by the bone meal ration than by the ration lacking this bone meal and which at the same time was abnormally low in calcium and in phosphorus. This was probably due to the neutralizing of the hydrochloric acid of the gastric juice by the mineral compounds of the bone meal fed, thus interfering with the digestion of proteids.

These facts indicate that bone meal will not serve all the bodily needs for phosphorus.

The muscles of the hogs receiving the bone meal contained less ash and less phosphorus in the ash but more ash in the protein than those produced without the bone meal and on a ration much lower in calcium and phosphorus. The bone meal may have increased the proportion of ash to protein in the muscles by its calcium taking the place of potassium or sodium in neutralizing the acids produced in the animal's tissues, thus allowing these mineral bases to increase the proportion of ash to protein in the muscles by contributing to this ash through solution in the liquids contained in the muscular tissue.

The peculiarities of the growth of the pigs fed on the rations especially low in phosphorus and calcium were that the bones increased considerably in size but decreased markedly in the percent of ash in the bone. There was very little increase in live weight and this increase was much more largely fat than muscle.

Thus we see that foods affect animals consuming them not only as to amount of gain made and relative proportion of fats, proteids, water and minerals but also as to the percentage of ash in the bone and both percent and composition of the ash of the flesh. In this connection it may be noted that any such circumstance as causes a modification of the relative proportion of liquids to protein in the flesh will change the composition of the ash of the same, since the ash constituents carried by the liquids of the flesh differ from those in the solids.

The well known effect of corn when fed in excessive amounts, to injure the breeding capacity of our farm stock and the egg-laying capacity of fowls, is doubtless due to its tendency to fatten. In fattening animals there appears to be a marked tendency for fat to accumulate internally in such manner as to cause pressure upon the female generative organs and thus to restrict the circulation of blood within them. This very often results in a loss of functional efficiency of the reproductive organs.

Thus the deficiency of corn in the protein and minerals needed for growth renders it unfit to serve as the only food of a breeding or growing animal, though we know of no reason why it should be entirely withheld from any animal if those nutrients which it lacks are provided in some other form. It is easier, however, to satisfy a breeding animal's appetite without giving it too much nutriment, with certain foods which are less concentrated than corn.

SPECIFIC EFFECTS OF MINERAL NUTRIENTS.

General considerations: The importance of the mineral salts in the vital processes of the animal cell lies almost entirely in their physical or physico-chemical properties. The chemical reactions in the body which constitute the physical basis of life take place between substances in solution, and it is by means of the electrical charges carried by the particles in solution that reactions are brought about.

Very slight amounts of the mineral salts, acids or alkalies in water, enormously increase its power to conduct electrical currents. Many of the organic compounds of cells do not possess this capacity and hence show less pronounced chemical properties. Their molecules are usually vastly larger and more complex than those of the inorganic compounds, and the speed with which they carry electrical charges is correspondingly slow, with such as possess this property at all. Accordingly they are, as compared with the inorganic constituents of the cell, chemically inert.

The mineral elements in the body are most of them strongly acid or basic, and their compounds have a tendency to become exceedingly active when in dilute solution; also the small size of the molecules of their simpler compounds allows them to pass freely through cell membranes that are impenetrable to many of the larger molecules of the complex organic compounds.

The mineral substances of animal tissues exist not merely in solution but partially in firm combination with the organic constituents. These mineral substances render chemically active the large and inert organic complexes to which they are bound. An appreciation of this fact led Mann* to say:

"So-called pure ash-free proteids are chemically inert and in the true sense of the word, dead bodies. What puts life into them is the presence of electrolytes," that is, bodies capable, as are inorganic compounds in solution, of carrying electric charges.

Through their peculiar attributes the mineral elements maintain a very important relation to practically all of the vital processes and they enter into the composition of every tissue and fluid of the body. We shall briefly note the more important of these functions.

1. **Constructive purposes:** Calcium, phosphorus, sulphur and iron are used in the formation of essential structures in the body; this is very much the largest use which the minerals serve. (See pages 141 to 151).

*Mann: Chemistry of the Proteids, p. 219.

2. **Carriers of gaseous products.** Through the affinity which iron has for oxygen, the iron-containing hæmoglobin of the red blood-corpuscles carries oxygen from the lungs to the tissues where it is to be used. In the tissues this oxygen and the carbohydrate nutrients of the cells are chemically united through the agency of the iron-containing components of the cell proteids. The addition of this oxygen to the carbohydrate nutrients causes them to break down into carbon dioxide and water, the constituents from which they were built up in the leaves of plants. The carbon dioxide is carried away from the tissues and to the lungs through the agency of the red blood-corpuscles together with the carbonates and phosphates of the blood serum. In addition to the production of carbon dioxide and water there is liberated, by the oxidations in the tissues, the energy which was used in the green leaves in binding together these components of the carbohydrates. This energy came, of course, from the sun. When liberated in the animal cell it is manifest in heat and in the various movements and processes which constitute life. Hence we see that iron is involved in the basic reaction of living tissue, the liberation of energy.

3. **Maintenance of neutrality or of necessary acidity or alkalinity.** As proteid substances are used up in the life processes of animals the sulphur and phosphorus contained therein give rise to the formation of sulphuric and phosphoric acids. These and certain organic acids must be neutralized in order to preserve the neutrality of the blood and tissues. The equilibrium existing in the blood between the alkali carbonates and the phosphates plays the leading role in this process.* In case of a deficiency of alkali salts ammonia will be split off from proteids of the body for a time, to neutralize these acids, but complete freedom of the food from alkali salts, for a few days only, will cause the death of an animal.

Very many of the vital processes such as the building up and also the tearing down of chemical compounds in animals take place through the agency of a group of compounds known as enzymes. They cause and facilitate profound chemical changes merely by their presence, the exercise of their influence not involving them in such ways as to use them up. Their activity requires certain degrees of acidity or of alkalinity and mineral salts assist in the maintenance of the necessary conditions.

4. **Control of muscles.** The control of both voluntary and involuntary muscles is accomplished through the proportion of calcium, magnesium, sodium and potassium salts acting upon them. The specific influence of the various salts present is at this time still the subject of much investigation and controversy.

* See Henderson: Am. Jour. Physiol., Vol. XV, p. 257 and Vol. XXI, p. 173 and Henderson and Black: Ibid Vol. XVIII, p. 250.

5. **Movement of liquids.** Mineral salts are of service in the movement of liquids throughout the body and its tissues, for example, from the alimentary canal into the blood and also the reverse of this action, and from the blood into the tissues and from the tissues into the blood, and from the blood through the kidneys. These results seem to be produced, at least in part, by the reactions between the cell proteids and the mineral salts acting upon them in dilute solution, in some cases causing increased penetrability by liquids and dissolved substances, and in others decreasing penetrability by precipitation of the proteids.

In this way the salts of foodstuffs act as laxatives and also affect the action of secreting glands; they also assist in the preservation of normal physical conditions within the cells by regulating their distention by liquids.

Jordan, Hart and Patten* at the New York Station have recently shown that it is the mineral constituents of wheat bran which makes it a laxative feed, for ruminants at least; freed from these salts bran is quite constipating. This seems to explain, at least in part, the well-known laxative effect of graham bread and discredits the idea that this action is due only to the mechanical character of the food.

6. **Stimulate vital reactions.** Mineral elements incite and facilitate vital processes involving the proteids by rendering chemically active compounds which without them would be inert.

7. **Assist in coagulation of blood.** Calcium in the blood is essential to its coagulation—a safety provision without which small wounds would result in death by bleeding.

8. **Solution of proteids.** The presence of mineral salts in the liquids of the body keeps in solution certain of their nitrogenous constituents, the globulins, which are not soluble in water.

9. **Digestion of proteids and fats.** Mineral chlorides furnish the chlorine of the hydrochloric acid in the gastric juice, pepsin being inactive except in the presence of hydrochloric acid. The mineral salts may also assist in the solution of certain proteids, thus preparing them for digestion.

In the intestine the alkali salts assist in the digestion of the fats. Most food-fats consist of what we call neutral fats, that is, compounds of fatty acid and glycerine, and in addition smaller amounts of free fatty acids. There is also in foodstuffs a group of compounds called lecithins which contain fatty acids combined with glycerophosphoric acid and a nitrogenous group called choline.

* Jordan, Hart and Patten: Technical Bul. No. 1, N. Y. Exp. Sta., 1906.

The fatty acids of the food-fat and those resulting from the action of enzymes upon neutral food-fats, unite with the alkali salts of the bile, the pancreatic juice and the intestinal juice (succus entericus) to form soaps, which emulsify the remaining neutral fats and thus, by breaking them up into fine particles, facilitate their digestions by enzymes. This digestion is a splitting of the neutral fats into fatty acids and glycerine. The lecithins are also split by the digestive enzymes into fatty acids, glycerophosphoric acid and choline. The fatty acids and soaps produced by the digestion of the fats and lecithins are absorbed mostly dissolved in the bile. The bile salts which are active in these processes are usually sodium salts of the bile acids and as ordinarily prepared contain lecithins. They dissolve food lecithins readily and thus prepare them for the digestive splitting process. Thus mineral salts are fundamentally involved in the digestion of fats.

After the absorption of the soaps, fatty acids and glycerin resulting from this process and the re-formation from them of neutral fats, the alkalies absorbed with them are re-excreted into the intestine and are used again and again in the same same way.

EFFECTS OF LACK OF MINERAL NUTRIENTS.

Considering the great diversity of functions served by the mineral elements it is at once apparent that in case of a protracted shortage of any of them the animal must suffer a profound disorganization.

Forster*, a German physiologist, first proved that animals can live but a few days on food that is practically free from mineral matter and, strangely, that animals will live longer if given no food at all.

Lunin† proved that this latter fact was due to poisoning from the sulphuric and phosphoric acids produced by the breaking down of the tissues in the animal's life processes. Normally these acids are neutralized, in part by the basic mineral salts contained in the food.

The symptoms shown by animals deprived of salts in the food are loss of appetite, general weakness, a staggering gait, muscular tremors, great irritability, convulsions and finally death.

Osteomalacia (malnutrition of the bones) often results from deficiency of calcium and phosphorus in the food. If the deficiency of mineral nutrients is not pronounced but is long continued the symptoms will be merely lack of development of those parts requiring the most mineral nutriment, namely, the bones. The

* J. Forster: Ztschr. f. Biol., Vol. IX, p. 297.
† N. Lunin: Ztschr. f. physiol. Chem., Vol. V, p. 31.

animal will lack size. Muscular growth and other proteid increase is also interfered with on two accounts; first, because the lack of the mineral constituents of proteid tissues and second, because the acids resulting from the breaking down of proteids in the life processes interfere with the carrying off of carbon dioxide by the blood by uniting with the alkali carbonates which normally figure in that process. This causes a retention of carbon dioxide in the tissues and blocks the process of oxidation. In mild afflictions the growth made by the animal consists very largely of fat; first, because the food is deficient in the mineral substances essential to the construction of proteid increase and second, because oxidation processes are so interfered with that no alternative remains in the disposition of nutriment, but to make it into fat. In severe cases symptons of asphyxia develop. A hog which has been grown on corn alone furnishes a familiar example of the kind of development produced by foods that are poor in mineral nutrients. Such an animal, as previously stated, is usually undersized, fine boned and over-fat.

MINERAL ELEMENTS IN ANIMAL BODIES.

Some idea of the necessities of animals for mineral nutriment may be got from a study of the mineral content of their bodies.

Lawes and Gilbert made a considerable number of analyses of the carcasses of animals and some of their results are summarized in the table below:

COMPOSITION OF CARCASS OF OXEN, SHEEP AND PIGS, CALCULATED FROM RESULTS OF LAWES AND GILBERT.

	Ox		Calf	Sheep				Lamb	Pig	
	Half fat	Fat	Fat	Thin	Half fat	Fat	Very fat	Fat	Thin	Fat
	%	%	%	%	%	%	%	%	%	%
Fat	19.1	30.1	14.8	18.7	23.5	35.6	45.8	28.5	23.3	42 2
Nitrogenous matter	16.6	14.5	15.2	14.8	14.0	12.2	10.9	12.3	13.7	10.9
Minerals	4.66	3.92	3.8	3.16	3.17	2.81	2.9	2.94	2 67	1.65
Water	51 5	45.5	63.0	57.3	50.2	43.4	35.2	47.8	55 1	41.3
Contents of stomach, etc	8 2	6.0	3.2	6.0	9.1	6.0	5.2	8.5	5 2	4.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Minerals	%	%	%	%	%	%	%	%	%	%
Phosphorus	.803	.677	.670	.488	.524	.454	.484	.492	.465	.286
Calcium	1.508	1.281	1.177	.944	.965	.846	.886	.915	.771	.455
Magnesium	.051	.037	.048	.034	.031	.029	.033	.031	.032	.019
Potassium	.170	.146	.171	.144	.140	.123	.131	.138	.163	.115
Sodium	.108	.094	.109	.090	.077	.072	.096	.076	.082	.054
Iron	.028	.017	.015	.026	.029	.024	.021	.018	.015	.009
Sulphur	.015	.013	.016	.021	.014	.012	.011	.016	.021	.012
Live weight, lbs,	1,232	1,419	258.8	97.6	105.1	127.2	239.4	84.4	93.9	185.0
Age	4 yrs.	4 yrs.	9.5 wks.	1 yr.	3¼ yrs.	1¼ yrs.	1¾ yrs.	½ yr.		

From the above table we deduce the facts that the percentage of ash in the carcasses of cattle may vary between 3.92 and 4.66; with sheep the percentages recorded vary between 2.81 and 3.17, and with swine between 1.65 and 2.67. On the basis of the live weight of the entire animal Wolff considered that the ash of cattle varies between 4 and 5 percent, sheep 2.8-3.5 percent and swine 1.8-3.0 percent. In general the fatter the animal the lower will be the percentage of ash, this because pure fat contains no ash at all. These figures do not accurately indicate the relative needs of these animals for ash in the food, this being controlled in part by the relation between the maintenance requirement of mineral matter and the rapidity of proteid increase.

With all three of these kinds of animals calcium and phosphorus predominate in the ash. In a general way four-fifths of the ash is made up of oxides of these elements. With cattle and sheep calcium exceeds phosphorus in amount to a greater extent than in hogs. This difference is due to the fact that in swine there is more muscular tissue in proportion to bone than in sheep and cattle, a greater part of the phosphorus in swine being in the flesh combined with other elements than calcium, especially with potassium. This idea is borne out by the higher percentage of potassium in the ash of swine than in the ash of sheep and cattle.

The ash constituents generally are low in swine because of the high percentage of fat and low percentage of skeleton.

COMPOSITION OF ASH OF HUMAN BODY.

Tissue	Bone	Calf muscles	Brain	Liver	Lungs	Blood	Milk	Lymph
Analyst	Heintz	Staffel	Breed	Oidt-mann	C. Schmidt	Verdeil	Wilden-stein	Dahn-hardt
Sodium chloride	.....	10.59	4.74	.....	13.0	58.81	10.73	74.48
Sodium oxide	.....	2.35	10.69	14.51	19.5	4.15	.....	.....
Potassium oxide	.....	34.40	34.42	25.23	1.3	11.97	21.44	10.35
Calcium oxide	37.58	1.99	0.72	3.61	1.9	1.76	18.78	3.25
Magnesium oxide	1.22	1.45	1.23	0.20	1.9	1.12	0.87	0.97
Ferric oxide	1.66	.....	....	2.74	3.2	8.37	0.10	0.26
Chlorine	.....	.....	.....	2.58	.....	8.37	.....	0,05
Fluorine	.....	.....	.....	.....	.....	10.23	.....	1.09
Phosphorus pentoxide	53.31	48.13	48 17	50 18	48.5	10.23	19 00	.....
Sulphur trioxide	....	.....	0.75	0.92	1.4	1.67	2 64	8.20
Carbon dioxide	5.47	.....	.....	.....	.....	1.19	.....	.....
Silicic oxide	.....	0.81	0 12	0.27	.....	.....	.....	.....
Potassium chloride	.....	.....	.....	.....	.....	.....	26.33	.....

From Beaunis Physiologie Humaine.

The percentage composition of the ash of certain parts of the human body is set forth in the above table.

Fresh bones contain about 22 percent of ash. Two-thirds of the dry fat-free substance of bone is mineral matter. This fat-free dry bone contains the following percentages of certain elements: phosphorus, 11.8 percent; calcium, 27.2 percent; and magnesium, .3-.6 percent.

Muscles contain from 1 to 1.5 percent of ash; brain about 1 percent; liver 1.1 percent; ox blood 8.4-9.2 parts of ash per 1000 and serum 8 parts of ash per 1000.

Voit* states that the bones of a man contain about 1400 grams of phosphorus, the muscles about 130 grams and the brain and nervous system about 12 grams.

Considering the distribution of the basic elements in animal bodies, sodium salts predominate in the blood, serum and lymph; potassium salts in the blood-corpuscles, muscles, brain and liver; calcium salts in the bones; iron compounds are found most largely in the red blood-corpuscles, lungs, liver and spleen; magnesium in the lungs, muscles, bones and nervous tissue.

Among the acid elements phosphorus occurs much most abundantly in the bones; in the ash of the various solids of the body about one-half is somewhat uniformly phosphorus pentoxide; sulphur is found in nearly all proteids but especially in hair and horn.

The mineral nutrients of milk are of particular interest, since if there has been no purposive adjustment of composition to the needs of the little animal, there must have been an adjustment in the other direction, of the kind and amount of growth possible to the young animal, in accordance with the normal composition of its food.

Thus Pröscher and Abderhalden† in Bunge's laboratory found that there is a definite relationship between the composition of milk and the rapidity of growth of the young animal for which it serves as food. This relationship is indicated by the following figures:

Species	Time in days for the new-born animal to double its weight	100 parts of milk contain—			
		Protein	Ash	Calcium	Phosphorus
Man	180	1.6	0.2	.021	.022
Horse	60	2.0	0.4	.086	.057
Cow	47	3.5	0.7	.114	.087
Goat	22	3.7	0.78	.143	.122
Sheep	15	4.9	0.84	.178	.127
Swine	14	5.2	0.80	.178	.135
Cat	9.5	7.0	1.02	....	....
Dog	9	7.4	1.33	.321	.223
Rabbit	6	10.4	2.50	.636	.437

Ztschr. physiol. Chem., 27, 594.

This table would indicate a purposive relationship of food to necessities for food such that the more rapid the growth of the animal the richer is the milk in protein and ash. The calcium content of the milk follows the same law.

*Voit: Hermann's Handbuch der Physiologie, Vol. VI, pt. 1, p. 80.
†Friederich Pröscher: Ztschr. f. physiol. Chem. 24, p. 285.
Emil Abderhalden: " " " " 26, p. 487.
" " " " " " 27, p. 594, 408, 457.

The slow-growing human infant is provided with comparatively little ash in its milk while the rabbit, which matures in a very few months, is reared on milk which is richer in ash than any other kind of which we know.

Sow's milk is richer in ash than the milk of the mare and the cow. This is in accord with the early maturity and rapid increase in weight which characterize the growth of swine. This also indicates the desirability of giving attention to the ash content of food for swine, for no other animals that we raise are fed so largely upon our lowest-ash grain food, namely, corn.

In accordance with this idea of an adaptive harmony between the milk and the needs of the young animal, we call attention to some analyses of cow's milk made at the New York Experiment Station by Dr. L. L. Van Slyke.*

The figures below exhibit the composition of milk solids from six breeds of cows:

	Fat	Casein	Sugar	Ash
Holstein	28.0	27.4	39.1	5.93
American Holderness	28.1	26.8	39.7	5.53
Devon	30.1	27.3	36.8	5.52
Ayrshire	27.3	26.3	40.8	5.34
Guernsey	35.1	24.7	35.0	5.16
Jersey	36.4	25.4	33.4	4.82

The names of the breeds in this table have been arranged in accord with the ash content of the milk solids. It will be noted that this also arranges the breeds at least approximately in order of coarseness of bone. There is a general correspondence between the ash content of milk-solids and the demand for bone food by the calf, though it is not impossible that the calf merely grows bone up to the limit imposed by the ash content of the milk solids.

The distribution of the ash constituents in milk products is a matter of considerable practical importance in the feeding and sale of these commodities. Cow's milk and its products contain the following percentages of ash:

Whole milk	.0074
Skim milk	.0074
Cream	.0061
Buttermilk	.0067
Whey	.0065

From these figures (quoted from Simon's Physiol. Chem. p. 443) it appears that skim milk is about as rich in ash as whole milk, while cream, buttermilk and whey contain somewhat nearly as much ash as the whole milk.

*N. Y. State Station Report for 1891, pp. 139-162.

MINERAL CONSTITUENTS IN MILK.

Species	Potassium	Sodium	Chlorine	Iron	Calcium	Magnesium	Phosphorus	Ash
	Parts per hundred							
Human	.066	.190	.047	.0006	.035	.004	.025	.20
Dog	.115	.058	.166	.0014	.325	.012	.222	1.33
Swine	.078	.058	.076	.0028	.178	.010	.135	.80
Sheep	.810	.064	.130	.0029	.175	.090	.128	.84
Goat	.108	.046	.102	.0025	.141	.090	.124	.78
Cow	.148	.072	.137	.0015	.119	.014	.083	.70
Horse	.087	.010	.031	.0014	.089	.008	.057	.40
Rabbit	.209	.147	.135	.0014	.637	.033	.435	2.50

Abderhalden: Lehrbuch der physiol. Chem. p. 395.

From these figures it appears that human milk is richer in potassium than it is in phosphorus. In all other kinds of milk the phosphorus is decidedly in excess of the potassium. This fact is in accord with the relatively more rapid development of the skeleton in the lower animals.

In general the greatest differences in the amounts of the mineral elements in milk that is rich in ash constituents and that which is poor in these materials are in the amounts of calcium and phosphorus.

Sow's, ewe's, goat's and cow's milk have somewhat nearly the same ash content. The amounts of calcium and phosphorus in the milk of these animals are in accord with the rapidity of development of the young but the potassium exists in quantities ranging in the inverse order. Human milk is about .2-.4 percent ash; cow's milk being .6-.8 percent ash.

The chief acid element of the milk of all species is phosphorus. The chief basic element in human milk is potassium but in most animals potassium is second in amount to calcium.

A considerable part, 53-72 percent of the calcium and 36-50 percent of the phosphorus, of cow's milk is combined with the caseinogen. A small portion of the calcium is present as a salt of citric acid of which Vaudin[1] found 1.5 grams per liter.

Most of the remainder of the calcium is present as a mixture of di-calcic and tri-calcic phosphates which is kept suspended by the casein. In milk casein exists as a neutral lime salt in suspension.

The importance of lime as a nutrient is indicated by the fact that cow's milk is somewhat richer in lime than is a saturated solution of lime in water.

Stoklasa[2] found cow's milk to contain .9-1.13 grams of lecithin per liter and human milk 1.1-1.3 grams of lecithin per liter. The cow's milk contained in all .79 grams of phosphorus per liter and

[1]L. Vaudin: Ann. Inst. Pasteur 8 (1894) No. 7, pp. 502-595.
[2]Ztschr. physiol. Chem. 23, 1907, No. 4-5, pp. 343-346.

human milk .19 grams per liter. Hence 5 percent of the phosphorus of the cow's milk was present in lecithin and 30 percent of the phosphorus of human milk was present in this compound. (Regarding the significance of lecithin see pp. 147-148).

Söldner found 25 percent of the phosphorus of cow's milk to be in organic condition while almost the whole of the phosphorus of woman's milk was organic.

Diffloth[1] found in milk 2 hours old that the phosphorus was 41.92 percent soluble, 46.28 percent organic and 11.8 percent insoluble. Increasing age and heating tend to increase the insoluble phosphorus at the expense of the soluble.

The significance of the several mineral elements in animal bodies is separately considered below:

Calcium. Calcium the oxide of which we call lime, is a very abundant constituent of the ash of animals. Three-fourths of the ash of the body is lime. Seven-eighths of the ash of bones is phosphate of lime. Von Noorden[2], on the basis of Katz's work states that there are less than 10 grams of calcium in the soft tissues of a human being and in the bones nearly 100 times as much. It is this 1 percent in the blood and tissues which plays so important a role in the control of musclar contractions, coagulation of the blood, etc, Sherman[3] calls attention to the fact that flesh, as an only food, is quite deficient in calcium, carnivorous animals making good the shortage by eating some bone along with the flesh.

We have no data as to the relative usefulness of organic and inorganic calcium compounds, but it is very well established that inorganic calcium compounds are digested and assimilated by animals.

Phosphorus. Phosphorus is one of the most interesting of the mineral elements found in animals because of the number of forms in which it occurs and because of the essential connection which it sustains with many of the bodily structures and processes. It exists in the body in a great many compounds belonging to at least four groups; namely, (1) inorganic phosphates, which occur throughout the body in solution in its fluids and also in the solid substance of the bones, (2) lecithins which are found in all plant and animal cells, (3) phosphoproteins, and (4) nucleoproteins, both of the last two classes also probably being constant cell components.

In the inorganic phosphates phosphorus is present as salts of the mineral bases, calcium, magnesium, sodium, potassium and iron.

In the lecithins phosphorus is present as glycerophosphoric acid.

[1]Abs. in Rev. Gen. Lait., 4, (1905) No. 13, pp. 308-310.
[2]Von Noorden: Metabolism and Practical Medicine, Vol. 1, p. 426.
[3]Sherman: Proc. Lake Placid Conf. on Home Economics, 1907.

Phosphoproteins, among which we classify casein, contain phosphorus but the condition in which it occurs is not positively known, at this time. It differs, however, from the phosphorus of the nucleoproteins, which occur mostly in cell nuclei, and in which phosphorus is present in nucleic acids.

According to Wolff there is in fresh flesh containing 25 percent of dry matter, .26-.35 percent of phosphorus. In the nerve tissues about the same amount is found, while in the blood, lymph and digestive juices the amount is much smaller, .044-.087 percent.

The author* has found in the tenderloin muscles of pigs .195 to .352 percent of phosphorus, the corresponding dry matter varying between 26.26 and 25.37 percent. In pig kidneys the phosphorus varied between .205 and .318 percent, the corresponding dry matter being 20.73 and 22.82 percent; while in livers the phosphorus varied between .291 and .367 percent with dry matter content of 28.52 and 28.35 percent.

As will be seen in the table on p. 142 there is in bone ash, phosphorus pentoxide to the extent of 53.31 percent, there being about 22 percent of ash in fresh bone. In pig muscle Forbes and Whittier found .217 percent total phosphorus, .154 percent water soluble phosphorus, .082 percent inorganic phosphorus, .0208 percent lecithin phosphorus and, by difference, .114 percent protein phosphorus. Thus of the total phosphorus .7 was soluble in water, .4 was inorganic, .1 was lecithin phosphorus and .5 was protein phosphorus.

Carnot† reports the following composition for the ash of the femur bone of man and cattle in parts per 1000:

	Man	Ox
Calcium phosphate	874.5	857.2
Magnesium phosphate	15.7	15.3
Calcium fluoride	3.5	4.5
Calcium chloride	2.3	3.0
Calcium carbonate	101.8	119.6
Iron oxide	1.0	1.3

There is difference of opinion as to the exact compound in which calcium phosphate occurs in living bone, but it is usually considered to be present mostly as the tri-calcic phosphate.

In nervous tissue a considerable part of the phosphorus exists in complex organic combination in lecithins and related bodies. The various compounds of this group contain about 3.70-4.00 percent of phosphorus, which is present as glycerophosphoric acid. Lecithin is sometimes prescribed as a medicine in cases of rickets and nerv-

* Bul. 81, Mo. Exp. Sta.
† Carnot: Compt. rend. Vol. CXIV.

ous exhaustion. The prominent place given eggs in the rest-cure treatment of nervous prostration probably has its foundation in the high lecithin content of the yolk of egg. A number of our common food-stuffs contain appreciable amounts of lecithin. In the digestive process its phosphorus is absorbed as glycerophosphoric acid. Within recent years the glycerophosphates have come into considerable prominence as drugs.

The function of the lecithins is not understood but some connection with the use of fats for energy production is indicated by their usual occurrence associated with fat in greatest amount wherever intense activity or rapid cell multiplication must be provided for, as in eggs, spermatozoa, gland cells and nerve centers. Miescher found 7.47 percent of lecithin in spermatozoa and 31.73 percent in their extremely motile tails. Lecithins are also found in all vegetable cells, especially in the germs of seeds. An opinion prevails among many experimenters in the field of physiology that the phosphorus of lecithin has a value as a nutrient that it has not in other compounds containing this element. A number of investigators have reported astonishing results from the use of the compound as a stimulant to growth, especially in those parts of animals containing most phosphorus, but the evidence upon which these ideas rest is much of it unsatisfactory. A large conservative group holds the belief that phosphorus in lecithin is not more useful than assimilable phosphorus in other forms. The subject needs further study, and is being investigated at this institution.

Inorganic phosphates are readily digested and assimilated and may be retained in the body and used for the various functions, including growth of bone, in which inorganic phosphates would appear to have a use. One must bear in mind the fact that three-fourths of the mineral matter of the body is inorganic calcium phosphate, found mostly in the bones, and that even in the flesh about half of the phosphorus is inorganic. A considerable part of the phosphorus of milk is also inorganic. It is true, however, that inorganic phosphates, particularly those of the stronger bases, are chemically inactive in the body. The field of their usefulness would seem to be restricted not so much by the fact that they are inorganic as by the fact that the mineral bases with which they are united have stronger affinities for the phosphorus than are possessed by the organic complexes which have need for phosphorus.

There is, however, a difference of opinion among physiologists as to whether or not any inorganic phosphates are useful in the synthesis of organic phosphorus compounds in the animal body.

Köhler[1] found precipitated calcium phosphate, bone ash and steamed bone all assimilable by lambs, the first preparation four times as completely as the last two.

Weiske and DeWild in 1873 found that if the food was sufficiently rich naturally, in phosphates, the addition of more to the ration did not result in added storage of the same.

J. Neumann[2] fed calcium carbonate and calcium phosphate to calves with good results. The phosphorus was retained in the body to the extent of 46.5-51.1 percent and of the lime 61 percent was retained.

From Wood's Therapeutics we quote the following: "According to Roloff a herd of cows which had been fed upon hay from a certain meadow were very much out of health and suffered from *fragilitas ossium*. On examination the hay was found to be nearly free from earthy salts, and upon bone-meal being given to the cows they recovered their health in four weeks. Haubner also affirms that cattle fed exclusively on potatoes, or upon roots very poor in phosphates, fail to fatten, become weak, and are apt to suffer from caries, but if the calcium phosphate be given they rapidly improve; and E. Voit states that rachitis without emaciation can be produced in three or four weeks in young dogs by taking the calcium phosphate out of the food. Böker has found that if calcium phosphate be given to those wet-nurses whose milk contains an abnormally small amount of phosphates the milk soon becomes rich in earthy salts."

The author[3] has fed raw bone meal and bone flour to pigs with the effect greatly to strengthen the bones. It also increased the density, the volume, and the ash per cubic centimeter of volume, of the bones. The increase in the size of the bones was at the porous ends rather than in the shaft. There was no appreciable increase in length of bone due to this feed. While other phosphorus compounds, such as phytin from wheat bran, caused a marked increase in muscular development, there was no observable indication that the bone meal was at all useful for this purpose.

About one-half or one-third only of the calcium and phosphorus of vegetable foodstuffs is utilized by animals, so that in computing rations it is necessary to allow for at least two or three times as much of these elements as the animal requires in its vital processes.

In the choice of compounds of phosphorus to feed to animals we have to bear in mind the following considerations:

1 The principal need for phosphorus in the body is for inorganic phosphorus.

1 Köhler: Landw. Versuchsstationen Vol. LXI, 1905, p. 451 and Vol. LXV, 1907, p. 349.
2 J. Neumann: Journ. Landw. 41 (1893) No. 4, pp. 343-380.
3 Bul. 81, Mo. Agr. Exp. Sta.

2 The smaller amount of organic phosphorus needed goes largely to support the formation of muscle, nervous tissue, gland cells, milk and reproductive substance.

3 Inorganic phosphorus seems to be able to supply the bodily need for inorganic phosphorus only.

4 Organic phosphorus can supply all the bodily needs for phosphorous, both organic and inorganic, if the necessary bases are present.

5 The phosphorus of vegetable foods is very much more largely organic than inorganic and hence in case of a deficiency of phosphorus in a ration the probability is that the principal lack will be satisfied by inorganic phosphates.

6 Inorganic phosphorus is cheaper than organic phosphorus and if fed in assimilable form and in combination with the bases that are needed, it will probably supply any ordinary deficiency in the phosphorus of the ration.

Iron. Iron is one of the most important and least abundant elements to be found in the body. According to Bunge there are in the human body about 3.2 grams of iron. This is one one-hundred-forty-second part of a pound avoirdupois. It is a necessary constituent of every cell in the animal. Eighty percent of the iron of the body is in the blood. Of the blood 14 percent is hæmoglobin and of the hæmoglobin one three-hundredth is iron.

In general the iron exists in the body firmly united with very complex nitrogenous compounds called nucleoproteins.

Nature stores up iron in the body of the unborn mammal in anticipation of the poverty of milk in this essential nutrient.* During the whole of the suckling period the little animal is drawing upon this reserve and lowering the percent of iron in its body. If a child is kept too long a time on milk alone it will become anemic. This is especially true of infants reared upon artificial foods, which usually contain only one-third or one-half as much iron as does human milk.†

Sodium. Sodium is present mostly as the chloride, common salt, but also as the phosphate and carbonate, especially in the fluids of the body. In the human body are about 200 grams of sodium chloride. About 16 grams of this salt leave the body daily. It is particularly prominent as a constituent of the lymph, blood-serum and urine.

* Bunge: Ztschr. physiol. Chem., 13 (1889) p. 399.
† Sollmann: Text Book of Pharmacology, 1906, p. 626.

An important function of sodium chloride is the part which it plays in the stimulation and regulation of the muscular movements. It is also important as a source of the chlorine of the hydrochloric acid of the gastric juice. Failure in the supply of sodium chloride leads to digestive disturbance.

In blood-serum sodium carbonate is also prominent and assists in the carrying of carbon dioxide.

Potassium. Potassium like sodium is present in the body mostly as salts of mineral acids, and also like sodium is important in its regulative capacity over muscular movements.

Unlike sodium, however, it is found mostly in the solids of the body rather than in the liquids, especially in blood corpuscles, muscles and liver, as the phosphate.

Magnesium. Magnesium is found in small quantities in the body, mostly in the bones and mostly as the phosphate. Only in the muscles is magnesium phosphate more abundant than calcium phosphate.

Sulphur. Sulphur is an essential constituent of most of the proteids of the body. One item of especial interest in this connection is that among the various nitrogenous tissues of the body hair is characterized by an especially high sulphur content.

MINERAL ELEMENTS IN FOODSTUFFS.

The ash of plants and animals consists principally of salts formed from calcium, sodium, potassium, magnesium and iron by combination with hydrochloric, sulphuric, phosphoric, silicic and carbonic acids. There is, however, no particular relationship between the compounds of the ash and the compounds in which the elements occur in plants and animals. As an instance of this fact, consider the element phosphorus which occurs in the ash of organic substances as various inorganic phosphates. In plants and animals it occurs in at least four different groups of organic compounds, (lecithins, phytates, phosphoalbumens and phosphoproteins) with considerable numbers of different combinations in each group, all of which are destroyed by the process of ashing, and in addition also as inorganic salts, which may be different from those of the ash.

The mineral substances of foodstuffs are present in four mechanical conditions; in solution in the plant juices, as crystals in the tissues, as incrustations in cells and in chemical combination with the living substance. Sulphur, phosphorus and iron* may occur as constituent parts of proteid molecules. The mineral content of any

*Czapek (Biochemie der Pflanzen Vol. I, p. 463 and Vol. II, p. 472) notes the current belief, based upon work of Macchiati, Molisch and Stoklasa, that iron is not a constituent of chlorophyl but on the authority of Petit and Suzuki states that it occurs in plant nucleins, and also cites the work of Spitzer and Sarthou who find iron in certain oxidases.

species of plant varies considerably as affected (1) by the composition of the soil and the soil water, (2) by the various factors controlling transpiration of water by the plant and (3) by loss of mineral substance either through shedding of parts or through the leaching effects of dews and rains.

A general method is to be seen in the distribution of the mineral substances in the various parts of plants. Leaves as a rule are rich in ash because of the mineral substances carried thither in solution and left behind by the transpiration of the water. Seeds and roots are comparatively poor in ash because of the storage in them of ash-free carbohydrates and fats and low-ash proteids.

The ash constituents of seeds and leaves differ in a general way, the mineral elements in seeds being largely those which are essential to the growth of the young plant, while a considerable part of the ash of leaves may be considered as residual and in no way essential. The mineral constituents of grains are much more largely organic than are those present in leaves.

MINERAL ELEMENTS IN VEGETABLE SUBSTANCES.

	Ash	Potassium	Sodium	Calcium	Magnesium	Iron	Phosphorus	Sulphur
	Parts in one thousand, dry matter basis							
1 Bluegrass	51 8	18 14	....	1.78	1 01	....	2.24	99
2 Timothy	68.2	19.64	.93	3.92	1 33	.40	3.52	.78
3 Red Clover (in bloom)	68.6	18.38	1 00	17.12	4.52	.52	2 89	.89
4 White Clover (in bloom)	73 2	13 06	3 93	15.78	4.18	1 05	4.09	2.17
5 Alfalfa (in bloom)	73.8	14 43	.96	21.46	2 19	.96	2.74	1.70
6 Winter wheat	19 6	5 07	.30	.46	1.42	.17	4.04	.03
7 Wheat bran	61 6	14 58	.30	1.27	6.62	.25	13.54	.02
8 Patent flour	5 1	1 45	.03	.25	.25	.02	1 11	....
9 Wheat straw	53.7	6 08	.55	2.21	.80	.23	1.13	.53
10 Barley	19.9	2.70	.61	.11	1.50	.24	2.85	.24
11 Oats	31.2	4.64	.39	.80	1.35	.26	3.49	.22
12 Oat straw	71.7	17.17	1.75	3.60	1.58	.58	1.44	.92
13 Corn	14.5	3 59	.12	.23	1.36	.08	2.87	.04
14 Cornmeal	6.8	1.63	.18	.31	.61	.19	1.34	....
15 Corn stover	53.3	16.06	.47	4.12	1.84	.86	1.93	1.13
16 Rice	3 9	.71	.16	.09	.27	.63	.91	.01
17 Rice bran	60.8	5.62	.96	.94	6.38	2.32	11.44	.09
18 Linseed oilmeal	58.4	11.79	.63	3.51	5.58	1.06	8.06	.76
19 Cottonseed meal	74 8	18.47	..	2.36	6.86	.67	15.01	.37
20 Soy beans	31 4	11 62	.23	1.19	1.69	....	5.03	.34
21 White beans	32 2	11.77	.36	1 54	1.48	.07	5 00	.52

From Wolff's "Aschen Analysen," Berlin, 1870 and 1880.

From the foregoing table we learn that potassium is the principal mineral element in the grass plants and in the roughage of both small grains and corn. Leguminous roughage, however, is characterized by very high calcium content.

In cereal grains the phosphorus is higher than in the roughage of the same species, and the potassium so much lower than in the roughage that potassium and phosphorous are approximately equal in amount.

In the milling by-products which contain the outer seed-coats potassium and phosphorus are both much higher than in the whole grain.

Winter wheat seems to contain four times as much ash as does patent flour and wheat bran twelve times as much. Wheat straw and wheat bran are not far different in ash content, but the bran is very much higher than the straw in potassium, magnesium and phosphorus. The cereal straws are high in silica. Considering minerals useful as nutrients patent flour is most deficient, as compared with whole wheat, in iron and phosphorus.

Rice, as we eat it, is exceedingly low in the mineral nutrients but rice polish is rich, especially in phosphorus.

Among the milling by-products wheat bran, rice polish, cottonseed meal and linseed oilmeal are rich in phosphorus.

Soy beans and white beans are richer than the cereals in potassium, calcium and sulphur.

In the following table, p. 154, we see that apples, gooseberries, strawberries and oranges contain from 14-30 parts of ash per 1000 parts of dry substance. They are not important as sources of mineral nutriment though it is of interest to note that strawberries and gooseberries are richer in iron, on a dry-matter basis, than the cereals, and that the ash of oranges is higher in calcium than is the ash of the other fruits.

The principal mineral nutrient in potatoes is potassium. The other essential elements are present in much smaller amount.

The comparison of the mineral elements in beets and beet leaves is interesting and instructive. The storage of carbohydrates in the root keeps its ash-content low, while the rapid transpiration of moisture by the leaves carries into them and deposits within them large amounts of mineral matter. These facts are true of root crops generally.

Turnips, cabbage, cauliflower and rape are all *Brassicas* and show their botanical kinship in their high sulphur-content.

The hen's egg is much poorer in potassium than most of the vegetable products. Relative to potassium it is much richer in sodium, phosphorus and sulphur than the vegetable products.

MINERAL ELEMENTS IN PLANT AND ANIMAL SUBSTANCES.†

	Ash	Potassium	Sodium	Calcium	Magnesium	Iron	Phosphorus	Sulphur
	Parts in one thousand, dry matter basis							
1 Apple	14 4	4 27	2 79	.42	.76	.14	.86	35
2 Gooseberry	33.9	10 87	2.49	2.96	1 20	1.08	2.91	80
3 Strawberry	34 0	5.94	7.18	3 45	....	1.40	2.05	.43
4 Orange	30.8	9.31	3 08	5.40	1.50	.26	1.49	.46
5 Potato	37 9	18 89	.83	70	1 13	.29	2.79	.99
6 Sugar beet	38 3	16.89	2 54	1.67	1 82	.31	2.04	.64
7 Sugar beet leaves	148 8	32.44	15.18	21 48	10 18	.56	3.09	3.16
8 Turnip	80.1	30 19	5.85	6.07	1 79	.45	4.44	3.59
9 Turnip leaves	116.4	22.63	8 16	27.39	2.78	1 29	3.71	4.38
10 Radish	156 7	28.58	4.36	9.84	3.52	1 27	28.14	4.84
11 Cabbage	96.2	35 68	5 81	8.35	2.10	.30	5.00	5.27
12 Cauliflower	83 5	30 74	3 65	3 33	1.85	.59	7.37	4.35
13 Rape	81.0	22 31	2 00	12 74	1.94	.66	3.93	4.53
14 Onion	52 8	14.92	.97	8.64	1 49	.84	4.00	1.20
15 Hen's egg	34.8	5.02	5.91	2.72	.24	.10	5.72	.04
16 Swine flesh *	....	9.38	5.75	.29	1.03	.20	7.84	7.52
17 Chicken flesh *	....	14.70	3.01	.34	1.17	.29	8.01	9.23
18 Steer flesh *	....	15.13	2 70	.09	1.00	1.01	7.02	7.81
19 Wool, scoured	11.1	1.76	.22	1.96	.40	1.41	.15	....
20 Wool, fleece	83 3	54 93	2.64	1.44	.28	.43	.37	1.58

* Katz: Arch. ges. Physiol., 1896.
† From Wolff's Aschen Analysen, except where otherwise noted.

Wool loses a very large part of its ash in the scouring process. The loss in mineral matter is largely potassium.

In judging of the nutritive values of foods it is necessary to consider not only the composition of the food but also the proportion of the ration which it constitutes; thus we gain an idea as to how much of this nutrient or that a given food will contribute to the ration. The phosphorus content of floury wheat middlings is very much lower than the phosphorus content of linseed oilmeal, but profitable rations composed of middlings and corn may contain more phosphorus than a profitable ration of corn and oilmeal. This is because the proportion of phosphorus to protein is higher in wheat middlings than it is in linseed oilmeal. The same principle holds good in regard to all nutrients, we must consider the relative amounts of the foods to be used in the ration.

In the manufacturing processes the grains are often so handled as to result in an uneven distribution of the mineral nutrients in the products. Most of the ash of grains is in the germs and in the seed coats.

Brewers' grains and malt sprouts are both decidedly higher in phosphorus than the grain from which they are made, but we do not know that this is in as useful a form for there is during germination a conspicuous change of the phosphorus from phytates to inorganic phosphorus.*

Gluten meal contains only half as much ash as does corn.

Hominy and bolted cornmeal contain only a small fraction of the ash of the corn from which they are made.

The rice we eat contains only one-third as much iron as the rice by-products fed to stock; rice polish which is fed to stock contains twenty-two times as much ash as the rice which we eat.

Wheat contains four times as much ash as does patent flour, while bran is three times as rich in ash as wheat.

Milk albumen and dried blood are practically pure-proteid foods, used for poultry, and are very deficient in ash while another milk feed, made from whey, contains twenty-three percent of ash, and feeding tankage often contains over twenty percent of ash.

Hence in the use of manufactured foods and by-products we find it imperative that we consider the amount and kinds of mineral substances which they contain, and when we shall know the specific effects of the compounds which contain the mineral elements in foodstuffs stock husbandry will hold out new rewards to the intelligent feeder.

The tables in Wolff's "Aschen Analysen" show the importance of certain factors as they affect the ash content of plants used for foodstuffs.

Among the grass plants (wheat, oats, rye, etc.) the ash content of the dry substance diminishes with the growth of the plant. The percent of potassium and calcium in the ash decreases, while the percent of silicon increases. The ash of thrifty plants is uniformly higher in calcium and lower in silicon than in unthrifty plants.

With clover the ash content of the dry matter decreases with the growth of the plant and so does the potassium, as with the grass plants, while the calcium and magnesium increase in the ash with the development of the plant.

* U. Suzuki, K. Yoshimura and M. Takaishi: Ueber ein Enzym "Phytase," das "Anhydro-oxymethylen-diphosphorsaure" spaltet; Bul. Coll. Agr., Tokyo Imperial University, Vol. VII, No. 4.

There is also an appreciable influence of the fertilizers applied to the soil, on the composition of the ash of the crops grown upon the soil. Other factors may mask this effect, but in general the mineral elements applied as fertilizers produce corresponding changes in the ash of the plants, more largely in leaves than in seeds.

Calcium in foods. The various preparations of bone and chalk contain more calcium than anything else used as food. Some brands of feeding tankage are also very high in calcium because of the amount of bone contained. Calcium is present in bone mostly as the phosphate. A cheap and easily assimilable form of bone phosphate is the precipitated calcium phosphate or bone flour produced as a by-product of the manufacture of gelatine.

Egg shells are also high in percentage of calcium since they are almost pure calcium carbonate. Oyster shell and chalk are also mostly calcium corbonate.

Among vegetable foods the legumes are particularly rich in calcium. In general, roughage is much higher in calcium than grains. Among grains corn is particularly low in calcium.

Among milling by-products those containing the outer seed-coats contain the most calcium; among human foods eggs, milk and legumes constitute our best sources of calcium; among fruits the orange and among vegetables the cabbage contain more calcium than others.

Particular interest attaches to calcium as a nutrient because of the fact that all grains are low in this element and corn the lowest of all the common ones of this country. Then, too, animals very commonly need more calcium than is present in the food, in order to grow strong bone as quickly as possible.

In considering the calcium content of foods we must bear in mind the fact that three-fourths of the ash of animal bodies is calcium.

Phosphorus in foods. Phosphorus in foodstuffs is found abundantly in bone preparations, tankage, wheat bran, cottonseed meal, rice polish, wheat middlings, buckwheat middlings, soy beans, malt sprouts, linseed oilmeal and those milk-sugar manufactory by-products which contain the ash of the milk. Milk and whey are also rich in phosphorus, on a dry matter basis. Rice polish and wheat bran are richer in phosphorus in proportion to their protein than any other vegetable foods in common use. The phosphorus in these foods is mostly in a condition to be especially useful in the formation of all tissues needing phosphorus. It is in a very easily soluble form called phytin.

Phosphorus is found much more sparingly in gluten meal gluten feed, dried blood, roots and roughage. Corn, oats and wheat contain moderate amonts of phosphorus, corn somewhat less than the smaller grains.

Among human foods those furnishing an abundance of phosphorus in the ration are milk, eggs, graham flour, beef, beans and peas. Those particularly poor in phosphorus are fat pork, bolted cornmeal, hominy, white flour, potatoes and rice.

Little is known as to the relative amounts of the different groups of phosphorus compounds in different foods. A few facts, however, are at hand.

In glandular structures such as liver and sweetbreads, a considerable amount of nuclein phosphorus occurs. This form of phosphorus is also abundant in the germ preparations of corn and wheat.

Phytin phosphorus constitutes most of the phosphorus of wheat bran and rice polish. This compound is very widely distributed in vegetable products but the amounts in which it occurs are not generally known in a definite way.

The phosphorus content of some of our common foods is given below:

PHOSPHORUS IN FOODSTUFFS.

	Percent		Percent
Potatoes	.03	Milk	.09
Hominy	.05	Linseed oilmeal	.80
Rice	.08	Soy beans	.82
Patent flour	.10	Wheat middlings	.90
Gluten meal	.14	Buckwheat middlings	.95
Dried blood	.19	Rice polish	1.17
Oats	.36	Cottonseed meal	1.17
Corn	.31	Wheat bran	1.26
Wheat	.38	Tankage	3.24

Interest is directed to the lecithin content of foods by the facts that all plant and animal cells contain this phosphorus compound and that a considerable part of the phosphorus of nervous tissue is in lecithin and related compounds. Among foods egg yolk is very much richer in lecithin than any other, containing about 10 percent. Meat meal contains about three percent; liver and kidney two and one-half; soy beans, muscle, brewers' grains, tankage and corn germ oilmeal between 1.8 and 1.0 percent in the order named. Linseed oilmeal, beans, wheat middlings, malt sprouts, barley and wheat contain between one percent and one-half percent, while oats, wheat bread and white of egg contain from one-quarter to one-fifth of one percent, and corn and milk from one-tenth to one-twelfth of one percent.

The phosphorus of grains is almost wholly organic. In roughage a much larger part is inorganic.

A knowledge of the amount and kinds of phosphorus in foodstuffs and of the specific effects of each when used as a nutrient by animals, would be of great practical value in the selection of foodstuffs for specific purposes.

Iron in foods. While the amount of iron in the animal body is exceedingly small so is its amount in foods also small. Its function in the body is exceedingly important and in certain abnormal conditions it becomes a matter of great practical importance that we consider the iron content of human foods.

In considering sources of iron in the food we naturally turn to the first food that the little animal gets— its mother's milk. We are in the habit of considering that milk is a perfect food, and so it is for some purposes but not by any means for all, because it is very poor in iron.

The foods that are our best sources of iron for human beings are vegetables and fruits generally, and cereal preparations such as contain the germs and the outer seed-coats of the grains.

Our foods richest in iron are in the order named—egg yolk, dried beans and peas, whole-wheat foods, spinach, raisins, oatmeal, beef and eggs. Those foods commonly in use which contain the smallest percentage of iron are milk, cornmeal, rice and wheat flour. Whole wheat contains four times as much iron as white flour. We have very little evidence as to the comparative availability of iron in these different foods.

IRON IN FOODSTUFFS.*

	Percent		Percent
Egg yolk	.0075	Cheese	.0015
Beans, dried	.0067	Wheat flour	.0013
Peas, dried	.0064	Grapes	.0013
Wheat	.0052	Asparagus	.0012
Almonds	.0047	Potatoes, peeled	.0012
Spinach	.0038	Cornmeal	.0011
Raisins	.0036	Barley meal	.0010
Oatmeal	.0035	Strawberries	.0009
Beef, round	.0032	Bananas	.0008
Eggs	.0030	Rice	.0006
Figs	.0030	Tomatoes, peeled	.0004
Prunes, dried	.0029	Apples	.0003
Peanuts	.0020	Milk	.00024
Dates	.0018	Oranges	.0002

* Sherman: Office of Exp. Sta., Bul. 185.

Potassium in foods. Potassium in vegetable foods is found in greatest amounts in roughage. Roots are low in potassium because of the high moisture content. Grains generally are low in potassium though soy beans are rich in this element. Grasses and clovers are nearly all rich in potassium, and among the mill feeds, linseed and cottonseed meal, bran, malt sprouts and brewers' grains contain an an abundance of this element.

While potassium is as necessary to animals as any other essential constituent, no particular interest attaches itself to this substance as a component of the food because, so far as we know, any practical ration will contain a superabundance of potassium. Among human foods fruit, vegetables, milk and meat are rich in potassium while the cereal products are low.

Magnesium in foods. Magnesium is more abundant in wheat and peas than in most foods. It is much more abundant in cow's milk than in human milk. It is not abundant in human milk or in hen's eggs. The necessary amount of magnesium appears always to be present in practical rations.

Sulphur in foods. Among the various families of plants the *Cruciferеae* are especially rich in sulphur. Among the common members of this family are cabbage, rape and turnips, plants which the shepherd regards as especially useful in the growth of wool of the best quality. The sulphur in these plants seems to be an important factor in the growth of wool. We may safely consider, I think, that the sulphur content of food proteids is sufficient for all needs except possibly where, as in sheep husbandry, there is a necessity for an unusual amount of sulphur.

Sodium in foods. Common salt furnishes us the sodium which the body needs. While many wars have been waged for salt, to supply the needs of human beings, it is at present so easily obtainable that even its mention seems superfluous, still we should know that it is as imperatively necessary to animals as any other essential nutrient.

THE FEEDING OF ANIMALS WITH REFERENCE TO MINERAL NUTRIENTS.

Our knowledge of the amounts and kinds of mineral matter required by animals is indefinite and fragmentary. Much progress has yet to be made in this field. Such recommendations as we are able to make should be regarded only as general indications of the truth.

The older works on stock feeding estimate the daily requirement of mineral nutrients from the amounts found in the body, dividing this quantity by the age in days. This, however, does not take into account the very considerable amounts of these nutrients which pass through the body in a steady stream, not being retained in considerable quantity, but doing wonderfully important work on their way.

Our knowledge of minimum requirements is much greater than our knowledge as to the maximum amounts that may be used with profit.

The maintenance requirement of mineral matter is comparatively slight; for growth it is very much greater; greatest among rapidly growing animals such as swine and poultry, and among mature animals such as laying hens and milking cows, which are fed for proteid increase. Pregnant animals also have greater need for mineral nutrients than do the same individuals when not pregnant.

The selective improvement of these same and other kinds of animals with reference to rapidity either of growth or of production of proteid increase, calls for amounts of mineral nutriment that were quite unnecessary in the days of unimproved stock, since the larger the production of proteid increase the higher must be the proportion of mineral nutriment in the ration.

In considering the use of certain nutrients, protein, probably, as well as minerals, we should not plan to follow too closely determinations of minimum requirements else we miss that last degree of excellence in results which distinguishes first-class from second class attainment. The profitable use of a liberal allowance of food requires of the feeder more intelligence than does a more conservative program, but he who knows and dares, wins. It should be our object to learn how much food we may use before added expense of production shall decrease net profits, per unit of investment and time, rather than how little we may use and "get along all right." This is especially true in regard to the mineral nutrients, where the uses of the elements involved are not wholly understood, but where we do know of a great number of exceedingly important services which they render.

The only mineral nutrient that we commonly accord the consideration which its importance merits, is common salt. This appreciation of salt, however, is not universal among the people of the earth* but is confined to those nations and tribes which live upon a mixed or a vegetarian diet.

Savage and semicivilized tribes of men, who live on animal food, do not use salt even when it is accessible. Their natural diet, especially the blood of animals, contains as much salt as they need,

* Bunge: Ztschr. f. Biol , Vol. 10, p. 111.

and these people have a very general dislike for salt. This is true of nomadic tribes in the north of Russia and Siberia, the natives of Kamtschatka and other primitive meat-eating folk.

Among vegetable feeders, however, both human and otherwise, the liking for salt is universal. Bunge relates that a vegetarian tribe, the Battas of Sumatra, mention salt in their legal oath, which is as follows:

"May my harvest fail, my cattle die, and may I never taste salt again if I do not speak the truth."

On account of the considerable number of ways in which salt is of service in the animal economy, few of them, properly speaking, being structural functions, it is not possible to say just how much salt an animal must receive in its food. Fortunately a moderate excess of this, as of most other mineral nutrients, does not do any appreciable harm. Wolff recommends that a cow receive half an ounce of salt per day.

Bunge* has shown us that potassium salts of acids other than hydrochloric acid, may cause an elimination of common salt from the blood by reacting with it to form other combinations, which may be either foreign to the blood or else, if normally present, may be formed in excess of the normal amount. In either case the undesirable substance, in the composition of which the sodium chloride of the blood has been used up, is excreted by the kidneys. Potassium salts very commonly predominate in the ash of plant substances used for food, and often require the consumption of considerable amounts of common salt to compensate the animal for the loss of common salt which they occasion.

After common salt the next most common mineral substance fed to stock is calcium phosphate in various forms. A good commercial form in which to get this substance is precipitated calcium phosphate, a mixture of tricalcic and dicalcic phosphates, the latter predominating. This preparation is made from green bone by treatment with hydrochloric acid, which dissolves out the bone earths, and precipitation of the same by milk of lime. This process is used to get rid of the mineral matter of bones in the manufacture of gelatine.

SWINE.

In the corn belt no animal suffers so severely from lack of mineral nutrients as does the hog. This is due solely to the prominence of corn in its ration. No other feed which is largely used has been proven insufficient as a source of mineral nutrients for

* Bunge: Physiologie des Menschen, Vol. II, pp. 103, 190.

hogs. The very general difficulty experienced by farmers in the corn-belt in keeping their hogs from running down in "scale" or size and in bone is doubtless due to their use of too little else than corn in the hog's ration. The profitable feeding of corn requires imperatively that the feeder consider in an intelligent way not only proteid but also mineral supplements. The feeding of wood ashes, corn-cob ashes, and charcoal is of decided benefit, though these substances are not by any means adequate to supply all the mineral nutrients required. The feeding of coal ashes has nothing to recommend it.

Those nutrients most needed by corn-fed hogs are calcium, protein and phosphorus. As a food for growing animals corn needs all these in order to produce normal developement of bone and muscle. Judging only by pounds of gain in weight per hundred pounds of food consumed, one might not appreciate the truth of these statements; a study of the carcasses of hogs, however, makes these points very plain and in the rearing of breeding stock this is a matter of the greatest importance.

Our proteid supplements to corn do not usually contain as much calcium and phosphorus as hogs need. It is usually desirable to furnish them with additional amounts of these elements in other substances. Some brands of feeding tankage, however, contain more than twenty percent of ash, most of which is bone. This bone furnishes calcium and phosphorus in available form and is a useful component of the feed. Bone flour is not especially well relished by hogs, though they will eat it if it is mixed with palatable feed. They like tankage very well, however, even when it contains as much as 22 percent of ash, mostly bone. Other forms of calcium phosphate are better relished and much more completely digested by animals than is bone meal or bone flour. Precipitated calcium phosphate, made from bones in the process of manufacture of gelatine is quite readily digestible. A meat meal containing its phosphorus in this form would leave little to be desired in the way of a complete supplement to corn for hogs. We have not as yet conclusive evidence as to whether corn and its proteid supplements contribute to the hog's ration as much phosphorus in organic condition as the hog needs. It is possible that if an abundance of inorganic phosphates were provided, as in precipitated calcium phosphate, the organic phosphorus of corn and its proteid supplements would be sufficient to serve all the needs of hogs for organic phosphorus. We shall be able to answer this question shortly.

Inorganic calcium, as found in chalk and bone preparations, seems to be able to furnish all the needs of hogs for extra calcium with the grain foods.

Proteid supplements to corn, which are especially rich in organic phosphorus, are wheat bran, wheat middlings, linseed oilmeal, soy beans and rice polish. Milk and whey also furnish calcium and phosphorus in readily available form, partly organic and partly inorganic. These are all practical hog feeds, though wheat bran is limited as to its usefulness by its fibrous character and by its cost. It makes an almost perfect ration by itself for brood sows, though unnecessarily rich in protein. A little corn fed with it will not make some sows too fat. For growing hogs bran is a useful feed if used in moderate proportion with more concentrated feeds. For fattening hogs it is too bulky. We can make more rapid and profitable gains from some more concentrated feeds.

The phosphorus in wheat bran is easily soluble in water, and the author has found that it has a marked capacity to support muscular growth in hogs.[1] In the same experiments bone phosphorus produced no perceptible increase in muscular growth. Phosphorus in both forms contributed to the development of the bones.

This water-extract of wheat bran may be pressed out and used to mix with dry feed for hogs which one wishes to grow rapidly. It is very palatable and may be made very rich in phosphorus. It is possible to give too much of it. This extract has been prepared by mixing bran with lukewarm water and soaking from one feeding time until the next, the hogs being fed twice daily. Two quarts of water were used in soaking each pound of bran. At feeding time the mash was put into a sack of thick cloth and a cider press was found useful for pressing out the liquid. One pound, or pint, of the extract with 2.5 or 3 pounds of feed, is not too much. This bran extract contained considerable ash for a liquid food, 53.0 percent more than the amount found in milk. It is richer in phosphorus, pound for pound, than corn and also contains considerable calcium, magnesium and potassium. The extracted bran may be fed to other stock. Jordan, Hart and Patten[2] found that the removal of its water-soluble constituents made bran a constipating instead of a laxative food for cows.

Clover and alfalfa hay and pasture grass are useful sources of mineral nutriment for hogs. Most feeders find difficulty in growing bone and muscle without grass and exercise.

The lack of mineral nutriment in the hog's ration often results in the animal breaking down on the way to market. It is often responsible, also, for the breaking down of sows with litters. The secretion of milk calls for more calcium and phosphorus than corn

[1]Bul. 81, Mo. Agr. Exp. Sta
[2]Jordan, Hart and Patten: Technical Bul. No. 1, N. Y. Exp. Sta., 1906.

contains. To make good the deficiency, the sow takes calcium phosphate from her own bones. This appears to cause a weakening of the tendenous attachments but may proceed until the shaft of leg bones fractures. These cases of breaking down of brood sows are curable without especial difficulty, unless fracture has occured, by taking away the pigs and feeding foods rich in calcium and phosphorus.

A young hog in one of the author's experiments, after several weeks on a low ash-ration, broke a leg, but made a complete recovery after a number of weeks on a high-ash ration.

Potatoes, roots and corn are especially low in calcium. A ration of milk and grain usually contains enough phosphorus but at least not an excess of calcium.

Kellner* recommends that a pig be given chalk as a source of calcium from the first week of its life. According to age, size and rapidity of growth he would give 5 to 12 grams of chalk per day. From a live weight at one year of age of 264 pounds, and a bodily content of .822 percent calcium and .48 percent phosphorus, he computes that the average daily storage of these substances is 2.72 and 1.62 grams respectively. He considers that three times these quantities will be enough to furnish the specified amounts in available form. When pigs are on a milk diet less than half this quantity will suffice. Considerably more than these quantities will do no appreciable harm if plenty of common salt is provided.

LAMBS.

H. Weiske† has conducted experiments in which lambs were reared from an age of four months to an age of a year and a half, the storage of mineral elements being determined in 45-day periods. The figures in the table below are the result of this work:

DAILY RETENTION IN GRAMS PER FIFTY KILOGRAMS LIVE WEIGHT.

Period	Daily gain in weight	Nitrogen	Calcium	Magnesium	Potassium	Sodium	Phosphorus	Chlorine
1	363	6.75	2.29	.21	3.39	1.45	1.00	....
2	271	5.16	2.69	.11	4.05	1.32	1.09	....
3	206	3.71	1.89	.31	4.17	1.22	.85	1.07
4	153	4.37	2.27	.31	3.67	1.29	1.46	1.07
5	86	3.06	1.79	.24	4.60	.94	1.75	1.41
6	63	2 94	1.90	.34	2.62	.76	1.37	0 99
7	85	3.77	1.88	.22	2.05	.71	1.78	0 91
8	95	3.09	1.89	.31	3.50	...	1.72	....
9	..	1.84	.41	.17	.63	.46	.017	....

*Kellner: Die Ernährung der landwirtschaftlichen Nutztiere, Berlin, 1907, pp. 569, 570.
†Landw. Jahrbücher, Vol. IX, 1880, p. 205.

From these figures Kellner computes that lambs do not need more than 15.7 grams of calcium and 10.9 grams of phosphorus daily per 100 kilograms live weight, which is equivalent to 7.14 grams of calcium and 4.95 grams of phosphorus per 100 pounds live weight.

HUMAN BEINGS.

Langworthy[1] publishes an estimate, based upon conclusions of Sherman and of Von Noorden, of the daily mineral requirement of an adult human being:

ESTIMATED AMOUNT OF MINERAL MATTER REQUIRED PER MAN PER DAY.

	Grams		Grams
Phosphorus	1.31—1.75	Calcium	.50 — .71
Sulphur	.8 —1.4	Magnesium	.18 — .30
Potassium	1.66—2.49	Iron	.006— .012
Sodium	2.97—4.45	Chlorine	6.0 —8.0

These are maintenance requirements for mature persons. Growing children doubtless need very much more of some, at least, of these mineral nutrients, although not so much as our growing farm animals, because of their slower growth.

There is an accumulation of iron in the body of the unborn infant, apparently in anticipation of the poverty of milk in this element. During the suckling period there is a gradual reduction in the percent of iron in the body, until at the age of about one year it reaches that of the normal adult.[2] Yolk of egg makes ideal food for supplying the additional iron needed at this time.

Women and children need more iron in their food than do mature men, since growth, lactation and pregnancy all call for more iron than is needed for mere maintenance. Lactation increases the need for iron to the extent of about one-third the maintenance requirement. Many physiologists believe that at the time of sexual maturity of female animals there is a withdrawal of some of the iron from the circulation and a storage of this portion in the reproductive organs in anticipation of its need. This would indicate the desirability of unusual attention to the diet at this time. (For the iron content of common foods see p. 158.)

Dietary studies show that most people get enough iron most of the time, but still on every hand we see anemic people, especially women and children at certain stages of their development. Anemia responds to medication with iron preparations most readily if the iron supplied in the food be liberal in amount.

[1]Langworthy: Yearbook Dept. Agr 1907, pp. 361-378.
[2]Sherman: Office of Experiment Stations Bul. 185.

In studying 20 American dietaries Sherman[1] found that about half of them contained less calcium than the body needs. About a third of them were low in phosphorus. These deficient dietaries could have been improved by substituting milk and cheese for a part of the meat (which without bone is deficient in calcium) and by using fruits and vegetables in place of part of the starch and sugar.

Beans, peas, milk, graham flour and eggs contain considerable calcium, and these same foods are good sources of phosphorus. Meat is rich in phosphorus but poor in calcium.

Those foods which we use in considerable quantity which are poor in the mineral nutrients are rice, hominy, bolted cornmeal, patent flour, potatoes, sugar and fat meat. If one makes large use of these foods he should also use others containing much more mineral nutriment.

The subject of mineral nutrients in the feeding of infants is one of considerable importance. In the use of artificial foods there is usually a marked deficiency in iron. Sollmann[2] states that human milk contains 3.5-7.2 mg. of iron per liter of milk, while artificial infant's foods generally contain 1.4-2.6 mg.

J. H. Kastle[3] makes a comparison of cow's milk and human milk as foods for infants, with especial reference to mineral nutrients and a summary of his results and observations is given below:

Cow's milk contains 3.3 percent of proteid while human milk contains only 1.7 percent. Cows milk contains .7 percent of ash and human milk .2 percent.

"While cow's milk contains from 2.5 to 3.5 times as much mineral matter as human milk, the ash of the two milks contain approximately the same amount of available alkali."

Thus human milk supplies to the infant a greater amount of available alkali in proportion to proteid than cow's milk.

"According to Williams[4] the fat of human milk contains a very high proportion of unsaturated fatty acids compared with cow's milk, in consequence of which it is, according to this author, more readily absorbable."

"During recent years it has been established, chiefly through the labors of Czerny and Keller[5] in Germany and Budin[6] in Paris, and confirmed by Brennermann[7] and Walls[8] in this country, that the proteids of cow's milk are practically as easily digested by the

[1]Proc. Lake Placid Conf. on Home Econ., 1907.
[2]Sollmann: Text Book of Pharmacology, 1907, p. 626.
[3]Am. Journ. Physiol., 22, p. 284.
[4]Williams: Bio-chemical Journal, 1907, p. 406.
[5]Czerny and Keller: Das Kindes Ernährung, Ernährungstherapie, 2d. Abt., Leipzig u. Wien, 1901.
[6]Budin: The nursling, English translation, by Malony, London, 1907.
[7]Brennermann: Journ. Am. Med. Assn., 1907, pp. 1338-1344.
[8]Walls: Ibid., pp. 1389-1392.

suckling as those of human milk, and that the digestive disturbances in infants which were formerly ascribed to the excess and indigestibility of cow's milk proteid are in reality due to an excess of fat."

"These authors have shown that an excess of fat in the food of infants results in the withdrawal of alkalies from the tissues by the fatty acids in the intestines, so that ammonia (withdrawn from the formation of urea) is ultimately drawn upon to neutralize the normal acid products of metabolism."

A second factor involved in the causation of the withdrawal of alkalies from the body is the excessive proteid destruction and excretion necessitated by the excessive amounts of protein in the cow's milk. This produces unusual amounts of phosphoric and sulphuric acids requiring to be neutralized by alkalies either from the food or from the body. This causes a rapid elimination of alkalies by way of the kidneys, and taken together with the loss of alkalies through the feces, caused by the difficultly absorbable fat of cow's milk in the intestine, produces symptoms of acidosis, gastero-intestinal disorders and malnutrition.

The loss of mineral matter through the feces of infants fed on cow's milk is indicated by the facts that while the feces of breast-fed babies were found by Wegscheider to contain 7.1-8.4 percent of ash, the hard, pale feces of babies fed on cow's milk were found by Forster to contain 34 percent of ash. The feeding to infants of skim milk and buttermilk, and the addition to the milk of certain alkaline substances such as citrates, and the dilution of cow's milk with barley gruel or with water containing white of egg and the use of orange juice, are regarded as good procedure.

The ash of white of egg and orange juice are shown to contain more available alkali than does cow's milk.

HORSES.

The quality of the bone of horses greatly affects their value and usefulness, and there seems to be ample justification for the popular belief that certain regions, famous alike for fine horses and for luxuriant pasture grass, owe their preeminence in these regards to the calcium and phosphorus content of the soil and of the forage crops.

Considering the rapid growth of the long bones of the colt's skeleton, the importance of dense bone as affecting the serviceability of horses, the prevalence of spavin and of other bone affections and the immense investment which there is involved in the horse-breeding industry, it would seem that this high-class business offers an unparalleled opportunity for the profitable application of the facts regarding the mineral nutrients, when they shall have been worked out to definite, practical conclusions.

While the importance of this subject is generally recognized we have not seen specific information regarding the use of the mineral nutrients with horses.

In our experience, however, it has been found that horses will take readily, if mixed with the feed, quite as much calcium and phosphorus in the shape of precipitated calcium phosphate as one would care to administer. It is a well-known fact that this substance contributes to the formation of bone in all our farm animals.

POULTRY.

Detailed information regarding the feeding of poultry, with reference to mineral nutrients, has not come to the author's notice though some work of a general character has been done at the New York and Rhode Island Stations.

Wheeler[1], at the New York station found that, for growing chicks, most grain rations are improved by the addition of bone ash. In these experiments oyster-shell was found to be less valuable than bone ash and rock phosphate.

These results indicate that, with young growing chicks, the need of a mineral supplement to grain rations is for calcium phosphate rather than calcium carbonate. The growing chick has small need for calcium carbonate in comparison with the laying hen. The former needs the phosphate for bone formation; the latter the carbonate for egg shells.

Bolté[2] at the Rhode Island Station has found that bone ash and calcium carbonate when fed with certain feeds increase their capacity to cause gain in live weight.

Calcium carbonate, usually fed to laying hens as oyster-shell is universally understood to be necessary to formation of the shells of eggs but little study seems to have been given to those mineral nutrients which are necessary to the formation of the inner portion of the egg.

The very rapid production of proteid increase by poultry warrants us in the belief that the subject of mineral nutrients is one of great practical importance in their feeding.

[1]Wheeler: N. Y. State Sta. Bul. 242.
[2]Bolté: R. I. Sta. Bul. 126.

CATTLE.

Soxhlet[1] experimenting with a 2-3 weeks-old calf weighing about 110 pounds determined the amounts of mineral matter taken into the body and retained therein. The daily food given was 8,093 grams of milk containing 62 grams of ash.

DAILY MINERAL INTAKE AND STORAGE.

	In Milk	Retained	
Ash	Grams	Grams	Percent
Whole Ash	62.05	32.89	53.0
Calcium	10.54	10.23	97.0
Magnesium	.82	.25	30.5
Potassium	13.04	2.70	20.7
Sodium	3.50	1.02	29.1
Iron	.07	.0265	38.0
Phosphorus	8.25	5.98	72.5
Chlorine	6.75	0.26	3.8

These figures indicate that the calcium content of milk may be a limiting factor in the growth of bone, and certain results from feeding experiments with young animals on a milk diet show that this conclusion is correct and that such animals will often profit by the addition of calcium compounds to the milk.

Weiske[2], experimenting with 5 to 6-months-old calves, on rations of hay and mixed grain feeds, found that they retained in the body 51-54 percent of the calcium and 56-65 percent of the phosphorus of the feeds.

Lehmann[3], experimenting with 5-months-old calves found that 42 percent of the calcium and 40 percent of the phosphorus of the ration were retained. He likewise fed hay and other feeds in variety.

Kellner[4] is of the opinion that while receiving milk a calf can use to advantage about 15 grams or half an ounce of chalk daily, and also that where the ration is straw, roots and grains, calcium is apt to be lacking. In case bone meal, or bone ash is used one should give 4-5 times as much of these as of the easily soluble phosphates.

Wolff[5] considers that with cows a lack of potassium in the ration is not a likely contingency. Calcium, however, in the form of chalk, should be added to the ration when the cows are fed entirely on such foods as straw, chaff, roots, potato slump and beet pulp.

[1]Soxhlet: Erster Bericht über Arbeiten der landw.-chem. Versuchsstation in Wien aus den Jahren 1870-1877, Wien 1878 S. 101.
[2]Weiske: Journ. für Landw. 21 Bd , S. 139.
[3]Lehmann: Landw. Versuchsstationen, 1 Bd., S. 68
[4]Kellner: Die Ernährung der landw. Nutztiere, p. 472.
[5]Wolff: Farm Foods, Eng. Ed., London, 1895, pp. 274, 275, 276

Kellner[1] states that the phosphorus content of cow's milk is .655 grams and the calcium content 1.29 grams per liter. From these figures and Henneberg's determination of 21.83 grams of phosphorus and 71.48 grams of calcium as the maintenance requirement per 1000 kg. of steer's weight, and considering the fact as proven by Weiske and Lehmann, that ruminants retain in the body only one-half or one-third of the calcium and phosphorus of the food, Kellner computes that dairy cows, yielding 20 kg. of milk daily, require per 1000 kg. of live weight about 143 grams of calcium and 61 grams of phosphorus in the ration. This is equivalent to 65 grams of calcium and 27.77 grams of phosphorus per 1000 lb. cow, giving 20 lbs. of milk per day. These figures are higher than previous estimates, because of a consideration of the above mentioned results of Weiske and Lehmann, and are doubtless, on this account, much nearer the truth.

The lack of mineral nutrients in the ration is most likely to occur in dry years when the poverty of the roughage in mineral nutrients is often so great, in many parts of the world, as to cause osteomalacia or malnutrition of the bones.

Ordinary changes in the mineral nutrients of the ration appear not to produce marked variations in the composition of the milk.

It is a well known fact that in many regions malnutrition of the bones, or osteomalacia as it is called, is caused in all the larger farm animals in dry seasons through the abnormally low calcium and phosphorus content of the grass and other forage at such times.

This poverty of the grass in bone-food seems to be due to the lessened transpiration of water by the grass during a drought. There seems to be less transpiration per pound of growth of dry substance in a dry season than in a wet one, other things being equal, and thus less mineral matter is carried into the plant in solution in the soil water.

The injury is most marked in young, growing stock and in milking or in pregnant females. Difficulty of this sort is common in many parts of Furope and South Africa and in the Hawaiian Islands. The feeding of bone preparations alleviates the difficulty, and in regions where the soil is naturally very poor in lime, as in parts of South Africa and the Hawaiian Islands, this treatment makes stock raising profitable where otherwise it would be impossible. It is

Kellner: Die Ernahrung der landw. Nutztiere, Berlin, 1907, pp. 569, 570.

quite possible that in this country stock would respond to similar treatment in dry seasons, though we have not heard of osteomalacia as prevalent in the United States.

The addition of 30-50 grams of calcium phosphate per head each day will usually cure the animal suffering from osteomalacia. The malady may be prevented by liberal use of phosphatic fertilizers on the meadows and pastures. This procedure not only adds to the calcium and phosphorus in the vegetation but encourages the growth of legumes.

In South Africa osteomalacia is known as "lamziekte." It has in this region caused great loss among sheep and cattle. The cause, according to Colonial Veterinary Surgeon Hutcheon, is the deficiency in phosphates of the natural herbage. Zuritz[3] in the Cape Colony comes to similar conclusions and publishes numerous analyses of sandstone soils which are exceedingly poor in phosphorus. Cattle grazing the veld will manifest an intense craving for bones while they suffer from this disease. Those animals most subject to the disease are heifers with first calf, milking or pregnant cows and growing calves. Mature oxen are not often affected. The prevailing method of prevention and cure is in this region the use in the food of finely ground raw bone.

Von Seelhorst (Journal für Landw., 1900) found that in dry soil clover contained 15.5—18.1 percent less phosphorus than in wet soils, and that fertilizing the crop also increased the percentage of phosphorus.

Kellner[1] found that the phosphorus content of roughage was abnormally low at times of epidemics of osteomalacia, and Karmsrodt, Nessler, Roloff, Dirks and Morgen also made similar observations.

Bongartz[2] concluded that the epidemic of osteomalacia in the spring of 1894 was due to the drought of 1893. He quotes analyses by Stutzer showing that the phosphorus content of common foodstuffs was abnormally low in this dry season.

PHOSPHORUS, PARTS PER THOUSAND.

Feeds	Year 1894	Normal
Stock Beets	.19	.35
Straw	.37	1.09
Hay	1.27	1.88
Wheat bran	11.13	11.74

[1]Kellner: Sachs. landw. Zeitschr. 42 Jahrg., 1894, S. 167.
[2]Bongartz: Fühlings landw. Zeitung, 1894.
[3]Zuritz: Agr. Journ. Cape of Good Hope, Vol. 33, No. 5, 1908.

At the Hawaiian Experiment Station, Shorey found that sisal grown on a coral limestone soil contained 40 percent of lime in the ash, while the same species of plant, grown on another soil which was poor in lime, contained only 7 percent of lime in the ash. This shows to what a marked extent the composition of the ash of plants depends upon the composition of the soil and indicates that the character of soil should receive attention in the selection of a farm upon which to carry on stock breeding operations.

Unpublished results from the extensive fertility investigations of Director C. E. Thorne of this station bear out this idea of the general similarity in composition of the ash of plants and the available mineral fertility in the soil.